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Electrical and Non-Electrical Environment of Wind Turbine Main Components

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SUMMARY

Focus on the development of offshore wind power, and expectations to turbines and substations to operate reliably under all conditions, causes interest in determining exactly what is unique about the wind turbine environment. If not properly dealt with, this environment can shorten the lifetime of the electrical components or even lead to catastrophic component failure.

In the present paper, results are presented from investigations on existing standards which give detailed descriptions of the environmental and operational conditions of wind turbine components. It is found that there is currently a lack of application standards for wind turbine electrical equipment.

Component-level environmental requirements as given in equipment-specific standards are compared with the environment described in the IEC's 61400 series concerning wind turbines.

Based on methods defined in IEC 60721, the non-electrical environment of wind turbine is described by means of specific classes. In the paper, new class combinations are suggested covering the different operating conditions the components are exposed to. The class combinations include factors of climatic, mechanical and chemical character. The factors occur in different severities and combinations based on the geographic location.

Finally the specific electrical environment of wind turbines is described based on intense measurements and analyses of the load current in different wind turbines at different locations. Very fast variations partly of considerable magnitude were found and quantified.

KEYWORDS

Wind turbines; Climatic, mechanical and chemical environment; Electric conditions, Load profile

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1. INTRODUCTION

An initiative has been undertaken by several Danish companies and universities in order to determine what state-of-the-art is within the definitions of the wind turbine environment and what characterizes the electrical and non electrical conditions which the electrical equipment used in turbines operates under. The investigations were mainly based on user experiences, operational data and existing standards for electrical power equipment plus specific applications standards. This paper reflects the main outcome of the work. A thorough description and discussion of the results can be found in [1].

IEC 61400 [2, 3] specifies environmental requirements for onshore and offshore wind turbine applications. The listed requirements are ambient conditions and do not consider the presence of an environmental control system and/or the effect on climatic conditions of locating the electrical components inside the tower or nacelle. Modern wind turbines generally include some equipment to maintain the temperature, and in some cases humidity. It is therefore considered that equipment should be chosen to meet the IEC wind turbine environmental requirements.

In this project, the component standards themselves were examined to see how their environmental requirements compare to the wind turbine environment described by IEC. The types of equipment considered here are generators, power converters, power transformers, and switchgear. Some non-typical environmental requirements are highlighted which may need to be specified for use in wind turbines.

A study of the IEC 60721 [4] series shows methods to quantify the severities of environmental factors such as the climate, presence of chemicals, and more, by assignment of severity classes.

A thorough description of the environment, the electric components are exposed to, has to include the wind turbine electrical environment as well. The electrical topics under consideration are power fluctuations, transient over voltages, and harmonic currents, which means both voltage and current based exposure of the components.

Under the studies, it became clear, that a general picture of the transient voltage and the harmonic current conditions is difficult to give. Some work is still ongoing to clarify these aspects. The present paper, therefore, will deal with load fluctuations only and an analysis will be presented of the loading conditions experienced by wind turbines.

2. ENVIRONMENTAL REQUIREMENTS FOR WIND TURBINE ELECTRICAL COMPONENTS

Component-level environmental requirements as given in equipment-specific standards can be compared with the IEC's 61400 series concerning wind turbines. Disregarding the many different configurations of wind farms, focus here is only on several key components as:

- Generators, may be synchronous, asynchronous (IEC 60034)
- Partial- or full-power converters (IEC 60146)
- Power transformers in tower, nacelle, or in an enclosure near the wind turbine (IEC 60076)
- Metal-enclosed switchgear in the tower or in a nearby enclosure (IEC 62271)

Something of interest is to see whether or not passing a component-standard implies compatibility with the 61400 series. Inconsistencies should be noted, as these are areas where a wind turbine manufacturer should make special requirements to component suppliers in order to comply with the IEC-described wind turbine environment.

In [1] the environmental requirements given in the component-standards are considered individually. Since a comprehensive description of the component and the wind turbines environmental standards would require considerable space, this paper only emphasizes the main aspects, in order to note areas where special conditions need to be specified.

All component standards contain a clause saying that if a product is intended for use outside of the given normal environmental conditions, extra specifications must be stated and agreed-upon by the manufacturer and purchaser as comparison between table 1 and 2 demonstrates.

	Max Ta	**Min Ta**	**Humidity**
Generator			
General	+40°C	-15°C	
Converter			
General	Daily average = +30°C Yearly average = +25°C Trans/storage = +55°C	Water cooled = +5°C Oil cooled = -5°C Trans/storage=-40°C	Min = 15% No condensation
Power transformer			
General	+40°C	-25°C	
Dry type	+40°C at any time Monthly average = +30°C Yearly average = +20°C	Outdoor = -25°C Indoor = -5°C Trans/storage = -25°C	Below 93%
C1		-5°C for operation	
C2		-25°C for operation	
E0			No condensation
E1			Occasional condensation, limited pollution
E2			Frequent condensation and/or heavy pollution
Switchgear			
Indoor	+40°C (ever) Daily average = +35°C	-5°C -15°C -25°C	RH = 95%, 2.2kPa RH = 90%, 1.8kPa

Table 1: Summary of requirements from component standards
(Ta: ambient temp.; C1, C2, E0, E1, E2: Transformer climatic and environmental classes)

	Max Ta	**Min Ta**	**Max RH**	**Other considerations**
Onshore	Normal = 40°C Extreme = 50°C	Normal = -10°C Extreme = -20°C	95%	
Offshore	Normal = 40°C Extreme = 50°C	Normal = -10C Extreme = -20°C	100%	Saline atmosphere, moisture, dripping water

Table 2: The wind turbine environment as defined in [4, 5]

After this comparison some conclusions can be drawn. In addition to compliance with the appropriate equipment standards, the following specifications should be made in order for wind turbine electrical equipment to comply with IEC 61400:

- All equipment requires specification for extreme maximum temperature
- Generators and converters require specification for extreme low temperature and high humidity
- All dry-type power transformers should be climate class C2 and at least environmental class E1
- Offshore dry-type power transformers should be environmental class E2 or E3
- Switchgear should be rated as class '-25°C Indoor'

While climatic parameters, such as temperature and humidity are the most commonly considered environmental factors, the very right column in table 2 already indicates that comprehensive environment concerns have to include chemical exposure, presence of dust or sand plus mechanical exposure like vibrations and handling under transport and installation.

For this, in the next chapter, the IEC's 60721 standard will be used in order to further describe the wind turbine environment in a uniform manner.

Detailed information about the relation between component-standards and requirements as found in the IEC 61400 can be found in [1].

3. CONSIDERING THE WIND TURBINE ENVIRONMENT THROUGH IEC-60721

In an attempt to align a description of the wind turbine environment with the work of IEC, the 60721 series of documents will be used. In this way it should be possible to easily communicate the environmental considerations that should be made when equipment is to be used in wind turbines. With these documents it is possible to give a thorough description, covering all environmental aspects. The main basis for our characterization is the IEC 61400 series, supplemented with advice from engineers both at DONG Energy, as well as parts of Danish industry.

IEC 60721-3-3 gives several classes regarding usage, environmental exposure and severity.

All classes mentioned in this paper are denoted starting with '3', indicating the usage category 'stationary, weather-protected', since the assumption is that all electrical equipment being considered is operated in the nacelle, the tower, or an enclosure near the tower, and therefore the relevant category is stationary, weather-protected.

The next parameter in the classes to be considered describes:

Climatic (K), Special climatic (Z), Biologic conditions (B), Chemical active substances (C), Mechanical (M), Mechanical active substances (S)

The last parameter is a number indicating the severity level of the exposure. Lower severity levels indicate mild conditions, higher severity levels indicate increasingly harsh conditions, and also typically imply compliance with any lower severity levels.

Example: Class '3B1' means stationary, weather-protected usage + biological exposure + low severity.

Since a comprehensive definition of all environmental classes would require considerable space, the authors have chosen in this paper to concentrate on the main outcome of the investigations: A definition of environmental class combinations based on the IEC 60721-3-3 methodology and user experiences.

Within IEC 60721-3-3, several popular class combinations are given, but none of them match well to the wind turbine environment. The environment described in IEC 61400 does not specify any climate control and for this, the climate will first be characterized without considering such a system. Table 3 suggests some class combinations for a wind turbine system with an uncontrolled internal environment.

Description	**Class combination (Nacelle)**	**Class combination (Tower)**
Onshore, rural	3K6/3Z2/3B1/ 3C1/3S1/3M3	3K6/3Z2/3B1/ 3C1/3S1/3M2
Onshore, desert	3K6/3Z2/3B1/ 3C1/3S3/3M3	3K6/3Z2/3B1/ 3C1/3S3/3M2
Onshore, mountain	3K7/3Z2/3Z12/3B1/ 3C1/3S1/3M3	3K7/3Z2/3Z12/3B1/ 3C1/3S1/3M2
Offshore	3K6/3Z2/3Z7/3B1/ 3C2/3S1/3M3	3K6/3Z2/3Z7/3B1/ 3C2/3S1/3M2
Offshore, floating foundation	3K6/3Z2/3Z7/3B1/ 3C2/3S1/3M5	3K6/3Z2/3Z7/3B1/ 3C2/3S1/3M4
Offshore, cold climate	3K7/3Z2/3Z7/3B1/ 3C2/3S1/3M3	3K7/3Z2/3Z7/3B1/ 3C2/3S1/3M2
Controlled internal climate	3K2/3Z2/3B1/ 3C1/3M3	3K2/3Z2/3B1/ 3C1/3M2

Table 3: Suggestions for wind turbine environmental class combinations made by the authors of this paper, demonstrating the use of IEC 60721-3-3.

Because there is currently no standardized requirement to control the environment within the nacelle, the first six environments in Table 3 imply that the environmental conditions outside the nacelle have a direct influence on the environmental conditions inside the nacelle.

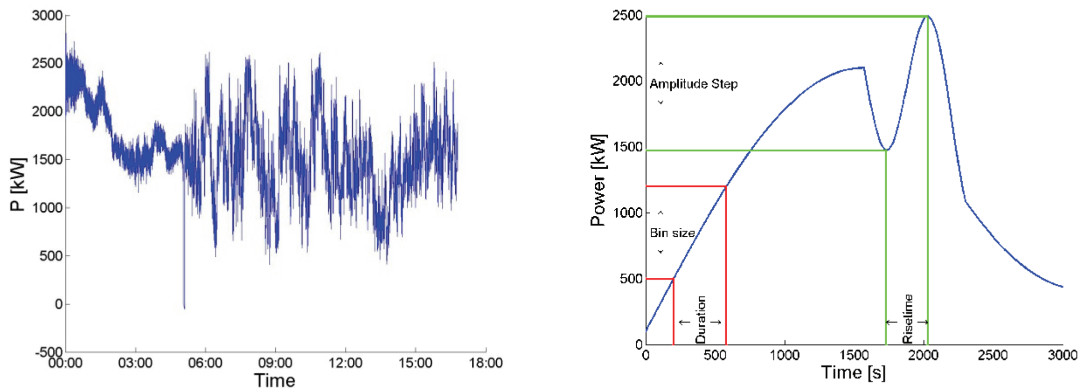
These class combinations represent the authors' assessment of the wind turbine environment. The implication is that environmental testing levels should be chosen to ensure that all electrical main components can operate safely under these conditions.

Detailed information about the definition of mentioned classes and their relation to wind turbine components can be found in [1].

4. ELECTRICAL ENVIRONMENT – LOAD ANALYSIS

The electrical operating environment of wind turbine components can be considered as somewhat unique because the power production of a wind turbine is closely related to the wind speed, the heavy fluctuations of which are well known.

The fluctuations can be considered as events characterized by the amplitude of the power, the duration of this power, the size of the power fluctuation, and the rise time of the power fluctuation. In a given time series of the power, the load condition can be characterized by the number of repetitions of the observed power fluctuation events. Fig.1 illustrates the principle and terminology used here.



(a) (b)

Fig. 1: (a) Example of the active power P measured on a wind turbine transformer over 17h. (b) Analysis: In order to be able to neglect small fluctuations such as the one shown in this figure, a user-defined threshold value was utilised by means of MATLAB® toolbox WAFO.

It is suggested that the electrical load conditions are characterised by dividing them into two parts, a static and a transient part. The static load conditions are concerned with the magnitude of the active power, the duration of it and the number of times the specific conditions are applied. The transient load conditions are concerned with the size of the magnitude changes in active power, the rise/fall time of the change and the number of times the specific conditions are applied.

Both the static and the transient load conditions are suggested to be displayed in three 3D histograms, which will give an orderly and comprehensive overview of the load conditions. Figs. 2 – 4 show the result for 2 offshore and for 1 onshore wind turbine, the data of which were measured every second over one year.

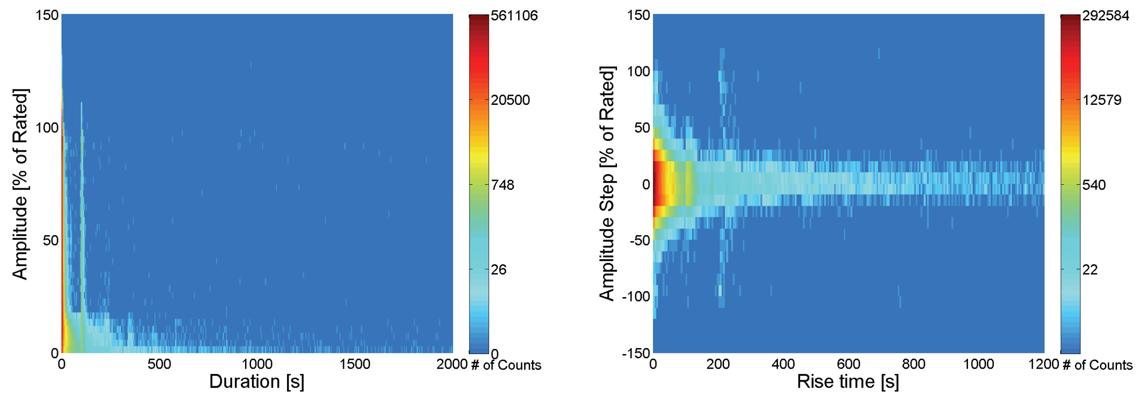


Fig. 2: Load conditions of the transformer of Offshore turbine 01 (OF01). The left figure shows the static analysis and the right one shows the transient analysis.

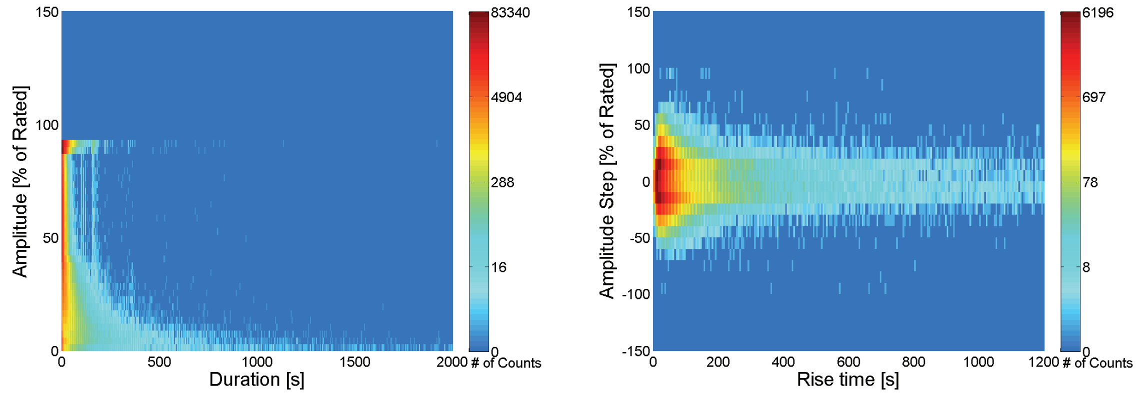


Fig. 3: Load conditions of the transformer of Offshore turbine 02 (OF02). The left figure shows the static analysis and the right one shows the transient analysis.

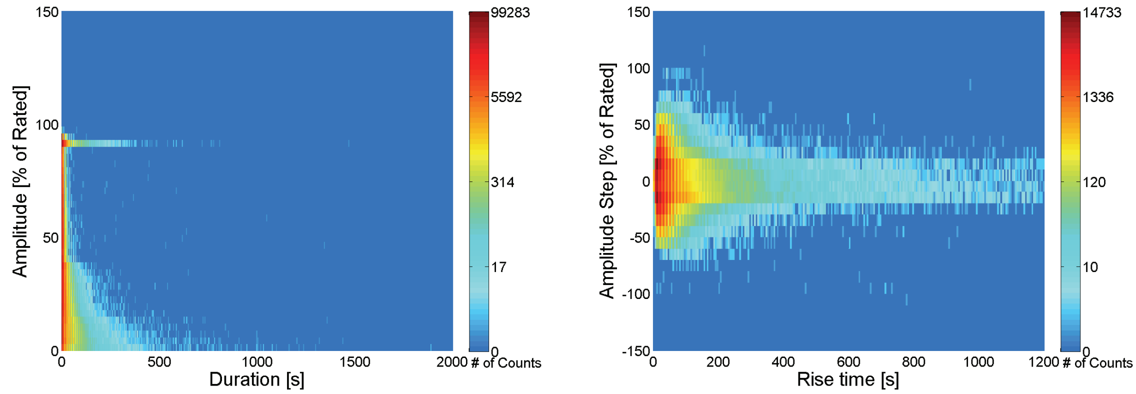


Fig. 4: Load conditions of the transformer of Onshore turbine 01 (ON01). The left figure shows the static analysis and the right one shows the transient analysis.

It is found that the power fluctuates considerably and only rarely stays at the same level for more than a few minutes (often only a few seconds). It is furthermore found that the power shows considerable amplitude changes over a year, with rise/fall times in the order of seconds, a characteristic which certainly differs from the common load picture seen in normal distribution systems.

For comparing the number of fluctuations, the number $NP_{50transient}$ is introduced. This quantity is the total number of active power (P) counts in the transient histogram with a threshold value of 50% amplitude step. $NP_{50transient}$ is shown in table 4 for each of the three turbines.

Turbine	OF01	OF02	ON01
$NP_{50transient}$	4403	1949	9125

Table 4: Number of power fluctuations of transient load analysis of the three turbines.

It is clear that the number of large load variations of the onshore turbine over a year is much larger than both of the offshore turbines. Whether this fact is globally applicable cannot be concluded on the basis of the few turbines analysed. However, the analysis shown above gives an easy tool for load comparison of different types of wind turbines/farms. A more detailed description of the methodology, the results and analysis can be found in [6].

5. CONCLUSION

The environmental conditions of the main electrical components in wind turbines, as generators, power converters, power transformers, and switchgear have been investigated.

Focus has been placed on the standardized environmental requirements of such components. It has been demonstrated that there is currently a lack of application standards for wind turbine electrical equipment. The existing wind turbine IEC standards do give a detailed description of the operational environment; however this is aimed at describing the external environment. These descriptions imply a very wide range of environmental conditions, which in several cases exceed the requirements of the relevant component standards. Nevertheless, there is currently no standardized requirement for a controlled internal environment for wind turbines.

Furthermore these factors occur in different severities and combinations based on the geographic location. If not properly dealt with, the operational environment can shorten the lifetime of an electrical component, or even lead to catastrophic component failure.

Many of these factors are mentioned in the documents IEC 61400-1 and 61400-3, but currently there is no clear description of the severity levels. In the present paper is described the usage of the IEC 60721 as a powerful method of giving a complete environmental description. Regarding the wind turbine environment new specific classes are suggested covering the different operating conditions the components are exposed to.

An introduction to the electrical environment of wind turbines is given in the paper as well, by intense measurements and analyses of the load current in different wind turbines at different locations, thereby demonstrating very rapid variations sometimes of considerable magnitude.

Systematic application of the method to a larger number of wind turbine types and locations is recommended.

6. ACKNOWLEDGMENT

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7. REFERENCES

[1] M. Henriksen, J. Holboell, et.al., "Wind Turbine Electrical Main Components, Electrical and Non-electrical Environment", Technical report of PSO project 010087, Technical University of Denmark, 2011.

[2] "Wind turbines - Design requirements", IEC Publication 61400-1, 2006.

[3] "Wind turbines - Design requirements for offshore wind turbines", IEC Publication 61400-3, 2009.

[4] "Classifications of environmental conditions - Classification of groups of environmental parameters and their severities - Stationary use at weather protected locations", IEC Publication 60721-3-3, 1996.

[5] "Power transformers – Part 16: Transformers for wind turbine applications", IEC Publication 60076-16, 2011.

[6] R.S. Olsen, J. Holboell, A. Jensen, "Analysis of load conditions of wind turbine components", EWEA Offshore, Amsterdam, 2011.